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MINISTRY OF HOUSING AND
LOCAL GOVERNMENT

Working Party on the Design and Construction of Underground Pipe Sewers

First Interim Report

LONDON
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The Working Party on the Design and Construction of Underground Pipe Sewers was appointed by the Minister of Housing and Local Government in June, 1964, with the following terms of reference: —

> "to investigate the practical application of structural theory to the design and construction of buried pipe sewers having due regard to structural stability, to watertightness and to economy in capital, operational and maintenance costs; to consider and advise on the relative merits of flexible and rigid construction over a range of ground and loading conditions commonly occurring in practice; and to initiate and co-ordinate research and experiment directed towards the production of reliable design data and the co-ordination of design and construction."

Membership. The following have been members of the Working Party since its inception:

R. A. Elliott, Esq., B.Sc., M.I.C.E. (Chairman).
R. R. Beaumont, Esq., M.I.C.E.
Granville Berry, Esq., M.I.C.E., M.I.Mun.E., A.M.I.W.E., F.I.E.S.
R. T. Gillet, Esq., B.Sc., M.I.C.E., F.R.S.H., F.I.P.H.E.
I. H. Hainsworth, Esq., M.I.C.E.
J. M. Haseldine, Esq., M.A., M.I.C.E., A.M.I.Mech.E.
H. P. Kaufman, Esq., B.Sc., M.I.C.E., M.I.Struct.E., F.R.S.H., M.Cons.E.
F. G. Martin, Esq., M.I.C.E.
J. B. Storey, Esq., M.I.C.E., M.I.Mun.E., M.T.P.I., A.R.I.C.S.
R. W. C. Yeo, Esq., B.A., A.M.I.C.E.
O. C. Young, Esq., B.Sc., A.M.I.C.E.
(advised by N. W. B. Clarke, Esq., M.Eng., M.I.C.E.)

They were joined in April 1965 by
Dr. A. C. Whiffin, B.Sc., M.Sc.(Eng.), Ph.D., A.M.I.Mech.E.

Administrative Secretary
T. C. George, Esq., M.B.E.

Technical Secretary
T. P. Hughes, Esq., A.M.I.C.E., A.M.I.Mun.E.

To the Right Honourable Richard Crossman, O.B.E., M.P.,
Minister of Housing and Local Government.

Sir,

1. We have the honour to submit to you our first interim report. We have met as a full Working Party on nine occasions, and have in addition spent several days visiting representative pipe manufacturing works and research establishments in various parts of the country. We have appointed a number of sub-committees whose activities are described in detail later in this report.

2. We are not yet in a position to make definite recommendations to you. Extensive study and experimental work are necessary before we can reach final conclusions and offer adequate guidance in accordance with our terms of reference. Nevertheless, we think it desirable that the many engineers interested in this subject should be kept informed of the progress of our work by the issue of this interim report.

Background to the setting up of the Working Party

3. Until comparatively recently it was general practice in this country to provide additional strength to sewer pipelines, which had to support the weight of backfill and surface loads transmitted through the soil to the pipes, by means of concrete bedding, haunching and surround, subject to some general rules. These rules were set out many years ago in the Ministry of Health Form K.29.

4. A basic theory for the determination of loads on buried pipelines, originating from studies carried out at Iowa State University (U.S.A.) by Marston, Spangler and Schlick, received consideration between April 1959 and February 1961 by an informal working party set up by Sir George McNaughton, C.B., then Chief Engineer of your Department, to review the adequacy of the K.29 requirements.

5. That working party did not issue a report but as a result of their activities it was decided that the K.29 requirements should be amended to provide for the use of the method of design incorporating these theories as an alternative to traditional practice. It was also decided that, since this method of design had not up to that time been extensively used in this country, some preliminary guidance in the form of an agreed document should be provided to enable suitable mention to be made of the alternative in the revised form.

6. To fulfil this purpose the Building Research Station produced National Building Study No. 32, which included information on the basic factors recommended for general use where detailed design criteria were not available and simplified tables incorporating these factors. N.B.S. No. 32 was intended to serve the purpose only temporarily until research and experience could provide more information regarding the extent and effect of loads likely to be encountered, and until the detailed method of design became better known. For this reason the design criteria suggested in it were intended to be generous and to provide a factor of safety in the worst conditions likely to be encountered. The new form K.29 and N.B.S. No. 32 were issued in December 1962, with a circular 62/62 intimating that more detailed reference to the new method would probably be incorporated in the British Standards Institution's Code of Practice for sewerage, currently in course of revision.

7. The difficulties in this context encountered by the code drafting committee appointed by the British Standards Institution to review this Code of Practice resulted in a request to you from that committee through the Institution to set up a special committee to initiate and co-ordinate research and experiment on the structural design and construction of pipe sewers. A similar request was made by the National Salt Glazed Pipe Manufacturers' Association.

8. Consultation with the Building Research Station, the Ministry of Public Building and Works, with consulting engineers and local authority engineers confirmed the urgent need for further study and investigation of the subject. Local authorities were now permitted by form K.29 to use the traditional rules for protection, to design from first principles by the Marston Theory, or to use the simplified tables of N.B.S. No. 32. The latter in many cases result in the use of substantially stronger pipes than those called for by the traditional rules, a situation which has led to some doubt and confusion in the minds of designers.

9. As a result we were invited to constitute a Working Party with the task indicated by our terms of reference.

Definitions

10. The terms of reference include instructions to us to advise on the relative merits of rigid and flexible construction over a range of ground and loading conditions commonly occurring in practice. To avoid confusion over the interpretation of "rigid" and "flexible" in relation to a sewer, we propose to define the meaning which we shall apply to these terms throughout this and any other report we may issue.

11. *As applied to pipes* we shall refer to them as rigid or flexible according to the degree of deformation which takes place before fracture or collapse occurs. This in turn is generally dependent on the material of which the pipe is made. We shall therefore refer to pipes of materials which fracture before significant deformation occurs, such as clayware and concrete, as "rigid". Pipes of materials which deform to a significant extent before collapse, such as pitch fibre, plastics, ductile iron and steel, we shall refer to as "flexible".

In adopting these generalisations we bear in mind that pipes of materials which would normally be regarded as being in the flexible category may move into the rigid classification if the wall thickness is increased sufficiently.

12. *As applied to a line of pipes* we shall use the following terms and meanings: —

"a rigid pipeline" will be a line of rigid pipes with rigid joints;

"a flexible line of rigid pipes" will be a line of rigid pipes with flexible joints;

"a line of flexible pipes" will be a pipeline made up of flexible pipes with any type of joint.

The purpose of a pipe sewer

13. The basic purpose of a pipe sewer is to enable sewage or surface water to gravitate to a point where it can satisfactorily and safely be discharged for treatment or disposal.

14. It must be so designed that, so far as this can reasonably be ensured, it will not be liable to cause damage, directly or indirectly, to life and limb or to other services or structures. Furthermore, it should be capable of ensuring that there is no escape of sewage which might pollute underground water and that the ingress of ground water to the sewer is reduced to minimal proportions.

15. In our terms of reference we are required to have due regard to structural stability, to watertightness and to economy in capital, operational and maintenance costs. These matters are interrelated in that the inadequacy of a sewer in any one of these respects is likely to result in inadequacy in another.

If a pipeline has inadequate structural stability, this is likely to result in higher operational and maintenance costs, and will naturally affect watertightness. Watertightness in itself can also significantly affect operational costs by virtue of increased infiltration into the sewerage system.

16. The relative importance of these matters, however, may vary substantially in different sewerage systems, according to such factors as the nature and size of the sewer, and the ground conditions in the area.

17. Structural stability is likely to increase in importance with size from the point of view of the physical consequences of failure, such as damage to property and danger to life and limb. It can, however, be of importance even from this aspect with small-diameter sewers where the nature of the subsoil is such that structural failure is likely to result in soil erosion and formation of cavities near the point of failure.

18. The importance of watertightness will depend upon the level of groundwater relative to the sewer, which will affect the degree of infiltration, and upon the location of sources of domestic water supply which might be affected by leakage from the sewer. It may depend also on the capacity of the sewerage system, whether storm water overflows are provided in it, whether the flow is pumped or gravitates to the point of discharge, and what proportion of the total flow is treated before discharge.

19. We do not suggest that design should be aimed at anything less than a structurally stable and watertight system, but we stress that true economy in capital, operational and maintenance costs may well depend on a reasoned decision as to the relative importance of these matters in each case, and a consequent decision on the degree of risk which may be accepted in the design criteria.

The task and the problems

20. Sewers are constructed in a vastly varying range of ground and weather conditions. A large range of materials may be employed, they may be constructed in many different ways, and they may be subjected to very different loads in different circumstances.

21. We regard our task as being to attempt to reach some conclusions as to a reasonable approach to the problem of design in the light of these facts.

22. The variables are such that sewer design can never become a purely theoretical exercise. We accept the need for a scientific basis of design, but we consider that practical considerations and engineering judgment based on experience must be given due weight by the designer, and that he must aim for a satisfactory balance between theory and practice.

23. In our early discussions of the task we have tried to consider in outline some of the many facets and variables in sewer design and construction so that we may plan our approach to the work. We set out below our immediate thoughts on these matters.

The 'customer'

24. Sewers and drains are constructed both by public authorities and by private builders. The range of work may extend from a contract for the construction of an extensive main sewerage system, carried out by a competent firm of civil engineering contractors under the expert supervision of experienced engineers, to the drainage within the curtilage of a single dwelling house, which may be carried out by an inexperienced builder without professional supervision.

25. Both types of contract are important in relation to the national economy, since the total annual expenditure on each is considerable.

26. There is, however, liable to be a basic difference in outlook between the public authority and the private developer. The former's consideration must include maintenance as well as capital cost; the latter's main concern will be capital expenditure, since maintenance will not normally be his responsibility.

27. This variation in approach is of fundamental importance in considering the problem before us. It might be suggested that to cater for it two sets of design and construction criteria should be produced, one for contracts likely to be carried out under satisfactory supervision, and one for work where such supervision is unlikely to be available. We do not consider that this approach to the problem is feasible. The quality of design and construction will vary from scheme to scheme, and to attempt to define ranges of quality within which different criteria should be used is in our view wholly impracticable.

28. We consider that, instead, we must attempt to suggest a sensible approach to the subject of design, bearing in mind deficiencies in workmanship which may be inevitable in some circumstances. It will then be for the individual engineer to decide to what extent he is justified in varying his design and specification because of the particular conditions in the problem before him.

29. It is stressed that a drainage system consists both of main public sewers and of private drains, and that the total length of the latter will almost certainly be many times greater than that of the former. It is not common sense to concentrate on producing a structurally stable, watertight sewer and to ignore the network of private drains which may be cracked and leaking. The design and construction of these drains is therefore quite as important as those of the main sewers. Inevitably, their construction is far more difficult to supervise, but expenditure on adequate supervision may result in substantial overall economy.

Sewer and drain sizes

30. Pipe sewers and drains may vary in diameter from 4 ins. to 72 ins. or more. This variation in size presents a more reasonable avenue of approach for the grouping of advice than does variation in workmanship and supervision. Whilst the same basic problems exist whatever the size of the sewer their relative importance is significantly different.

31. It is considered therefore that it may be practicable to divide sewers into some arbitrary size ranges; for each range economical and practical considerations will call for different design and constructional treatment. We are not yet able to define the size ranges into which we shall in our later reports attempt to divide our recommendations, but we have made inquiries in an effort to assess quantitatively the relative importance in this country of the various pipe sizes.

32. Although we have been unable to obtain precise information on this matter from the manufacturers of pipes of some materials, we have concluded that a preponderant proportion of the mileage and the capital investment on pipe sewers and drains in this country is in the range of smaller sizes, i.e. 9 ins. diameter and under. It so happens also that this size range is likely to include most of the drains designed by those with least skill and experience, and constructed with the worst quality of workmanship and least supervision.

33. We shall endeavour therefore to consider and advise on the problems associated with this range of pipes as soon as possible.

34. In suggesting, however, that some priority should be given to these we do not underestimate the importance of the larger sizes of sewers, but we bear in mind that many of these are designed with great care, practical experience and knowledge by eminent engineers. In due course we shall hope to add something to the basic knowledge on which these designs are undertaken, but we consider that the larger sizes of pipe sewers should always be regarded as complex engineering structures, the design of which should be undertaken only by those qualified to do so.

Materials

35. Engineers are faced today not only with designing to cater for modern loading and constructional conditions, but with an ever increasing choice of materials for sewer pipes. This is a desirable advance and we do not suggest that they should confine themselves only to the use of traditional materials.

36. We have, however, some doubts whether there is at present sufficient collaboration between manufacturers and users of sewer pipes. Manufacturers tend to encourage the engineer to accept what they offer rather than to produce a pipe to suit his requirements. When they offer a new product they are not always in a position to offer positive advice based on proven field experimental experience on how the pipe should be laid to attain the characteristics required from it.

There is an equal tendency for engineers to accept products as they are offered, to write into their Standards and specifications the strengths and other characteristics which they possess, and to adapt their design and construction methods to the products. They appear in some cases to be prepared to accept new materials without definitive advice regarding methods of construction.

We consider that increased market research should be encouraged and that engineers must be prepared to tell manufacturers precisely what they expect of the materials for a sewer or drain. It would then be in the manufacturer's economic interest to produce a product whose strength would be fully used, and to state the constructional requirements necessary to attain this strength.

There should also be a financial saving in that the need for variation and adaptation of constructional methods would be reduced.

We accept that there are practical limitations to what can be done, but we shall be considering whether it is not proper for engineers to adopt a course more closely aligned to a statement of requirements than an acceptance of an offer.

37. Progress is continually being made in the control of the quality of materials used for sewer pipes. Improvements in manufacturing techniques are leading to greater dimensional accuracy, greater strength, more strength ranges or classes, and pipes more uniform in all their characteristics. All these advances are making the task of the design engineer simpler in that, at least in theory, he has stricter guarantees as to the limits to which he can work. British Standards are continually under revision and new Standards are being produced with stricter definitions of structural strength and other characteristics.

38. Despite this progress, however, we are not wholly satisfied that enough emphasis is being placed at the present time on ensuring not only that a Standard exists but that products are manufactured and supplied in accordance with it. So much dependence is now placed by engineers on British Standards, which are in many cases regarded as a guarantee of quality, that we consider it vital that this implied guarantee should be fulfilled. We have no wish in any way to criticise the British Standards Institution in this matter, but we hope for the opportunity of discussing this problem with them.

39. There are many existing materials in general and increasing use regarding which there is inadequate information about constructional requirements and long-term behaviour in the ground. We consider it urgently necessary and are arranging to institute investigation and research into matters connected with some of these materials, and hope as a result of this work to be in a position to offer guidance to those who elect to use them.

Dimensional tolerances

40. We are of the opinion that insufficient attention is being given to dimensional tolerances in sewer pipes, and we consider this to be a matter of great concern. We have been informed of instances where the act of joining, with a flexible joint, pipes of the same manufacture has resulted in the fracture of the socket. We are also informed that it is not always possible to obtain specials of the same strength and dimensions as the pipes between which they are to be installed.

We realise that some difficulty arises because complete standardisation may involve manufacturers in costly re-equipment, and because of the many different types of flexible joint which are at present available.

We nevertheless consider it essential that eventually the dimensions of pipes and specials of the same material and strength shall be strictly standardised, and that only such dimensional tolerances shall be permitted as will not prevent the use of pipes and specials from different manufacturers in the same pipeline. We suggest that active steps should be taken now to this end although it may be some years before it is fully achieved.

Pipe lengths

41. The improvements in manufacturing technique to which reference has been made are also resulting in a general tendency to increase the lengths of pipes of traditional materials. We consider that this is an acceptable advance in that it reduces the number of joints on a pipeline, which should reduce the cost and the risk of leakage. Nevertheless as pipe lengths increase the advantages will at some stage be offset by increasing difficulties of handling and laying and risk of fracture. There will be an optimum length of pipe for each material, diameter and ground condition which will be revealed only by practical experience, and we shall watch closely and with interest this aspect of sewer construction, in the hope in our later reports of being able to offer our views.

Gradients

42. The gradients at which sewers are laid vary greatly and are in many cases dictated by topography and the level of existing works.

43. Our attention has been drawn to some instances in which there has been a tendency for large-diameter pipes laid on granular beddings of certain gradings to settle after construction. It has been suggested to us that too much stress may have been placed in the past on the maintenance of a true and defined gradient on a sewer between adjacent manholes. Whilst we accept that in certain instances and with certain types of sewer a minor variation from level may not be of significant importance, we do not accept that it would be proper to specify in such a way that such variations were generally accepted. The stage at which variation from level becomes significant varies from sewer to sewer and we do not consider it practicable to lay down tolerances which would be generally acceptable. Furthermore, once a departure from true gradient was permitted the contractor's task could be made more rather than less difficult in that he would not have a firm and definite specification to which to work. We consider, therefore, that engineers should continue to specify and require sewers to be laid at definite gradients and that only constructional methods which cater for this requirement should be used.

44. It has also been brought to our attention that some engineers have in the past specified gradients so flat that the tolerances permitted in the pipes themselves by the appropriate British Standards make it impossible for the contractor to adhere to the specification. It is obviously necessary for designers to bear in mind practical limitations in stating their requirements.

Pipe joints

45. The use of mechanical joints with rigid sewer pipes has increased substantially in recent years and large numbers of different types of joint are being introduced onto the market. Great stress has been placed on the flexible properties of such joints, and we accept that in many circumstances it is advantageous to provide flexibility in a sewer pipeline.

46. At the same time, we consider that perhaps the primary factors leading to the increasing use of mechanical joints are not the flexibility which they provide, but the speed and ease with which they can be made on site, their reliability, and the fact that when they are used the pipeline can be tested and the trench backfilled without delay. Increased mechanisation and lack of

skilled site labour, to which reference is made later in this report, stress the advantages of the use of joints as near foolproof as possible so far as construction is concerned.

47. We have, therefore, no doubt that the mechanical joint will eventually become universally used and we welcome the development. We note that your Department periodically issues a list of joints which have been tested and which they approve, and we consider that engineers would be well advised to consult this list.

48. Some question has been raised recently regarding the life of rubber rings in mechanical joints, arising from reports of degradation received from abroad. As yet insufficient evidence is available to enable us to comment on these reports. However, it is clearly desirable that the components of a joint should have a life equal to that of the pipe on which the joint is used. It is to be hoped that manufacturers will concentrate on this problem and will make every effort to provide products with this end in mind. If any material proves to be deficient in this respect there will be considerable difficulty in persuading engineers to use in the future what is claimed to be an improved modification of the original product.

49. We note that a mechanical sleeve joint is being developed for pipes of materials traditionally constructed with spigots and sockets. If this proves successful it appears to be a significant advance, since the elimination of collars from pipes will remove a potential point of weakness both in manufacture and construction and will eventually, it is hoped, effect a reduction in the cost per unit length of pipe. It should also facilitate the insertion of an angle branch into an existing sewer when arranging for the junction of a drain to the sewer, and will reduce the risk of damage to the sewer during this operation.

The bedding of sewer pipes and the use of extra strength pipes or concrete protection

50. Whatever method of design is adopted, the overall structural strength of a pipeline will depend on the strength of the pipes themselves and the type of bedding employed. Advances in manufacturing technique have provided the engineer with a wide range of pipe strengths and it is now open to him to provide adequate overall structural strength by using a stronger pipe and a bedding with a lower supporting strength, or a weaker pipe and a bedding, supplemented if necessary by all-round protection, with a higher supporting strength.

51. Once, therefore, he has decided on the overall strength he requires, and to this reference is made later, he must decide the combination of pipe strength and bedding and/or protection he will use. The principal factor in this decision will be overall economics, but bound with it will be many other matters, such as ground conditions in the area and availability of materials, skilled labour, mechanical plant and supervisory staff.

52. It is contended by some that the use of extra-strength pipes offers advantages over providing strength by way of in-situ concrete surround, in that strict control of materials is easier to achieve in the factory than on the site. They submit that it is difficult to predict the precise strength which can

be achieved by in-situ surround, since this depends largely on the quality of workmanship on the site, which is difficult to control.

53. Others contend, however, that as the strength of a pipe increases so do its weight and cost, the latter steeply. They submit that difficulties of handling and laying are likely to increase as pipe size and weight increase, and that these matters must be borne in mind in assessing the balance between facility of construction and economics.

54. We have insufficient information as yet to advise on the relative importance of these arguments, but hope to institute inquiries and if necessary experimental work to enable us to give some guidance on the relative merits of the two approaches to the problem.

55. With regard to bedding, in the past it was the general practice in this country to bed sewer pipes either on the natural trench formation or on concrete. In comparatively recent years the alternative of providing granular bedding has been introduced and its use is increasing.

56. In our preliminary consideration of the various forms of bedding we found significant variations and shades of opinion amongst ourselves regarding the relative advantages of each. We conclude that this is to be expected, since each of us has constructed sewers of different ranges of size in varying ground conditions and in different parts of the country, and the merits of particular beddings will vary with all these factors. It is our opinion that it will never be possible and would not be proper for us categorically to advise the use in all circumstances of a particular type of pipe, e.g. extra-strength or standard, with or without concrete protection, or a particular type of bedding. The requirements and comparative economics of the possible combinations of pipe strength and bedding will vary with every individual scheme and in the ultimate it will be for the engineer to reach his decision, within structural strength requirements, from his knowledge of the various factors affecting each individual case.

57. However, we hope that it may in due course be possible to offer general advice as to the factors particularly to be taken into account, and the likely relative economics and constructional advantages of the different combinations of pipe strength and bedding related to various groups of ground conditions and size ranges. We will work to this end by practical investigation and by comparison of relative costs, so far as this is possible.

Methods of construction

58. There have been significant changes in recent years in the methods employed in the construction of underground pipe sewers and drains. The section of the civil engineering industry concerned with this work is, in common with other branches, utilising more mechanised plant and less manual labour every year. This trend is accompanied by an ever-increasing lack of skilled labour, and the industry seeks design and constructional methods which will cater for this development.

59. The use of mechanical plant makes certain factors more important than they have been in the past. For example the cost of the plant makes it essential for the contractor to be able to work continuously despite bad ground and weather conditions.

60. The full employment of mechanical plant, greater speed of construction, less dependence on weather conditions, and reduction in the need for the skilled labour which is in such short supply offer economic advantages which might well make the total cost of a scheme lower, even though the use of such plant results in the need for more expensive materials and fittings.

61. We accept that this trend to mechanisation will continue and that it is the duty of the engineer to design sewers for which modern constructional facilities can be fully employed, and to cater for the limitations imposed by mechanisation. We consider that this requires a fresh examination of the economics of sewer design and construction and we shall bear this in mind in our discussions and final recommendations.

Standards of workmanship and supervision

62. Reference has already been made to the range of types of contract encountered in sewer and drain construction. The lack of skilled labour is being offset to some degree in large contracts by mechanisation and the use of modern materials and jointing methods. In the small contracts carried out by individual builders, however, there is less compensatory influence of this nature.

63. Both types of scheme are affected also by the ever-increasing shortage of skilled engineering staff for supervision. It is unfortunate that again the small contract is likely to suffer first and most from this shortage.

64. The object must therefore be to devise techniques for construction and to use materials which reduce to a minimum the unpredictable human element in construction and supervision. This will be one of our principal aims and is a matter which we shall bear particularly in mind in the early consideration which we hope to give to small-diameter sewers.

65. We consider that the shortage of adequate supervisory staff makes it essential for engineers to examine carefully the specifications which they issue to contractors. It is misleading and tends to lower the general quality of workmanship for an engineer to write into a specification a requirement which he does not in practice expect to achieve or intend to enforce, and the greatest care should be taken to specify only what is in fact required, and then to see that it is attained.

Structural requirements for rigid pipelines and flexible lines of rigid pipes

66. The traditional design method for rigid pipelines and flexible lines of rigid pipes has been to provide additional protection with in-situ concrete in specific circumstances of depth, size or location according to certain rules.

The current requirements laid down in form K.29 are as follows:

(a) Pipes of 30 ins. diameter and under with 20 ft. and more of cover in trenches to be surrounded with at least 6 ins. of concrete. Pipes of more than 30 ins. diameter under the above conditions may require additional concrete protection.

(b) Subject to (a) all pipes with over 14 ft. of cover to be bedded on and haunched with at least 6 ins. of concrete to at least the horizontal diameter of the pipe. The splaying of the concrete above that level to be tangential to the pipe.

(c) Subject to (a) all pipes of 18 ins. diameter and over to be bedded and haunched with at least 6 ins. of concrete to at least the horizontal diameter of the pipe. The splaying of the concrete above that level to be tangential to the pipe.

(d) Subject to (e) all pipes under 18 ins. in diameter and with less than 14 ft. of cover may be laid without concrete, if the joints are of the socket or collar type.

(e) All pipes with less than 4 ft. of cover under roads (except roads formed of concrete) or 3 ft. not under roads, to be surrounded with at least 6 ins. of concrete.

(f) In all cases the filling or concrete support must be well rammed and consolidated at the sides and haunches of the pipe. Selected filling should be used up to at least one foot above the top of the pipe.

67. These requirements were prepared many years ago and were based largely on practical experience of the capability of pipelines as constructed of carrying the fill and superimposed loads which were expected at that time to be imposed on them. It will be noted that no indication is given in the requirements of the strength of pipe to be used or of the concrete strength to be achieved, and no precise thicknesses are laid down for the protection of larger sizes of pipe.

68. In recent years circumstances and outlook have changed significantly in the social, economic, manufacturing and constructional spheres. The social changes have resulted not only in increases in quantity of sewage but indirectly also in the superimposed loads which sewers have to carry. Traffic loads for example are now in many cases far greater than were ever anticipated when the rules were laid down. Also, when current revisions of British Standards are completed the strengths of standard pipes of many materials will be known.

69. We accept, therefore, that these rules may require revision or extension, and that in modern conditions the previously accepted approach to sewer design may not always be good enough. A sewer pipeline is a structure and it is clearly necessary to adopt a rational approach to its design as such, so far as this is practicable in the light of the large number of variables entailed.

70. Despite the desirability of this approach we consider that it would be wrong to replace well-tried methods, rule of thumb or otherwise, by some rational method purely because it is rational. Before we advise the adoption of any particular method we must be satisfied that it results in a sewer pipeline of adequate but not extravagant strength.

71. There are three principal problems to be faced in advising on the adoption of such a method:

(a) to obtain practical proof of the theory involved;

(b) to choose basic design data to be used in the application of the theory;

(c) to determine the practicability of special design for individual schemes.

72. Rational design involves the determination of the total external load which the pipeline may have to support, and the selection of a pipe of suitable strength which it is calculated will provide sufficient supporting strength to

bear the total calculated load without damage in the bedding conditions to be employed.

73. The theory for the determination of the loads to be carried which is recommended in N.B.S. No. 32 originates from the work of Marston, Spangler and Schlick at Iowa State University (U.S.A.). Almost all the semi-empirical factors used in this design method are also those suggested by these three engineers as a result of their experimental work. It is probably the rational theory for pipe design which is most widely used in the world today, although we have not yet been able to assess the extent to which it is in fact practised.

74. The experimental work on which the theory is based was carried out principally between about 1909 and 1933, and most of the work on sewers in narrow trenches appears to have been carried out in the earliest experiments, with the facilities then available.

75. The method of determination of supporting strength of a pipeline and the bedding factors suggested in N.B.S. No. 32 also originate from work carried out at Iowa in about 1920, supported by experiments at Ohio as recently as 1955.

76. In recent years experimental work has been carried out in Russia by Emilianov and in Germany by Wetzorke, as a result of which each of these engineers has put forward a design theory as an alternative to that of Marston.

77. We have no wish or grounds on which to criticise the Marston theory, but we have found no record of pipes designed according to it being tested to destruction in field conditions, or of any recent work to determine the actual loads imposed on pipes in working conditions using modern pipes and present-day traffic loads and speeds.

78. We consider that before we can recommend the adoption of this or any other theory we must obtain reliable up-to-date experimental evidence of its efficacy, and that this can only be obtained by full-scale field experiments. We realise that this work will be costly, will take some time to complete, and that there may well be a considerable scatter in the results obtained. Nevertheless, it is felt that the attempt must be made before we can give adequate guidance on this matter, and as will be seen later in this report arrangements are now being made for tests of this nature.

79. Further research is also necessary to enable us to advise on the second problem, i.e. to choose basic design data to be used in the application of any structural theory. We have in mind particularly the traffic loads to be catered for, the impact factors associated with such loads, and the bedding factors of various bedding materials. Experimental work is needed to improve knowledge of the transmission of moving surface loads to underground sewer structures, and of the effect of impact in producing transient stresses in the structures. We are already co-operating with the Ministry of Transport and the Road Research Laboratory on experiments directed to this end, which are also referred to later in this report.

80. The third problem, i.e. the practicability of special design for individual schemes when a satisfactory theory has been proven, cannot in our opinion be the subject of a generally applicable decision. The need for precision in structural design for individual schemes must depend on the importance of the scheme and on the cost of design as a proportion of the cost of the works.

For the smaller and far more numerous schemes a set of design criteria which must inevitably be largely empirical but preferably having some acceptable basis combining theoretical, experimental and practical considerations, is the only workable answer, and our efforts will be directed to this end.

81. We note with interest that with small-diameter sewers (say up to 9 ins. diameter) at normal depths, design by the Marston theory with the factors suggested in N.B.S. No. 32 indicates that there is unlikely to be any great difficulty in attaining structural stability with modern pipes laid on most forms of bedding. This bears out such information as we have so far been able to obtain regarding the incidence and causes of failures of sewer pipelines, and increases our hope of being able to offer some guidance regarding the design and construction of this size range without undue delay.

Progress to date

82. In addition to our preliminary consideration of the various matters we have listed, we have visited a research establishment concerned with the ceramic industry and were impressed by the facilities available and the work being carried out. We have also visited firms manufacturing clayware pipes and firms manufacturing concrete pipes. In each case the firms concerned were representative of the most advanced sections of their own industry, and we were again impressed with the improvement in manufacturing techniques and the control of quality which were being effected. We hope to extend our visits to smaller firms representative of these industries, and to the manufacturers of pipes of other materials.

83. We were also glad of the opportunity of a discussion with Dr. Ing. M. Wetzorke during a recent visit he paid to this country. The following points of interest regarding sewer construction in Germany were brought out during the interview:

(a) sewer pipes are laid either on the natural trench formation or on concrete;

(b) although there is considerable evidence of pipe failures this is confined mainly to pipes of 15 ins. diameter and over;

(c) it is believed that more than half the failures are due to bad workmanship;

(d) only two or three cases have been reported of damage to pipes with concrete protection;

(e) cement mortar joints are forbidden;

(f) in most cases the traffic loads assumed for design purposes are considerably lower than those on which N.B.S. No. 32 is based;

(g) experiments have indicated that an impact factor of 1·5, compared with the figure of 2 adopted in this country, will give adequate security for design purposes.

Referring to the Marston theory, Dr. Wetzorke submitted that this has been based on the assumption that the total load in the plane of the crown of the pipe is transmitted to the pipe, i.e. that the fill at either side of the pipe does not take up any of the load. This gives high load values for the pipes. If Marston's load value applied in reality, large sections of the pipe network in Germany would already have failed, or would be operating at marginal safety factors.

As a result of his own experiments, Dr. Wetzorke differs basically from Marston in that he considers that the filling material at the side of the pipe will bear some of the load, and that the total trench load will not therefore fall on the pipe. Emilianov of Russia also contends that only part of the load at the crown is transmitted to the pipe, the rest being transmitted to the trench walls by an arching effect. Emilianov's formula has been found by Dr. Wetzorke to give a satisfactory factor of safety.

Dr. Wetzorke agreed that the degree of compaction of the sidefill is likely to affect the proportion of load taken by it. Even with poor compaction, however, the sidefill should take up stress approaching the value calculated by Emilianov.

Appointment of sub-committees

84. Arising from the consideration of our terms of reference we appointed at an early date four sub-committees, each of which has met on a number of occasions.

Sub-committee No. 1

85. This is a fact-finding sub-committee charged with the task of reporting on the extent and nature of research in progress or in contemplation connected with pipe sewer design and construction. Its appointment arose from our wish to ensure that research resources are used as fully as possible and that needless repetition of work in different establishments is avoided.

86. The sub-committee have been in communication with a large number of research and educational establishments and pipe manufacturers' associations in this country, and have sought information from sources in Australia, Canada, New Zealand, the U.S.A., Denmark, France, Germany and Israel.

87. It has been found that at certain universities in this country there is some basic research in progress indirectly connected with the design of underground pipes, e.g. investigations into problems in soil/structure interaction. One university is also carying out field experiments on a pipeline undergoing subsidence in a mining area.

Two of the pipe manufacturers' associations are carrying out limited laboratory experiments on the behaviour of their pipes in certain trench and loading conditions. Research establishments connected with the pipe-making industry are carrying out programmes designed to improve the integral strength, uniformity and quality of their products.

88. The inquiries abroad show that the American Concrete Pipe Association have a project under way to "survey the state of the art of computing loads on pipelines and to prepare recommendations for future research". The National Clay Pipe Institute of America are in the early stages of an extensive programme of research on the extent and type of loading on underground pipelines. In Hamburg, Wetzorke is now carrying out research to establish stress and load effects in wide trenches, and with several pipes laid in the same trench. It seems probable that other research is being carried out abroad, particularly in America, but it is difficult to trace; the sub-committee are continuing their efforts to this end.

89. They have concluded from their investigations that there is very little research work in progress in this country directly pertinent to our terms of reference. They have received offers of assistance in research from a number of establishments, which are much appreciated and of which it is hoped in due course to take advantage. They will continue to record information regarding research so that we may attempt to co-ordinate the efforts of all those interested in and intending to work on any subjects connected with the design and construction of underground pipe sewers.

Sub-committee No. 2

90. Early in our discussions reference was made to reports of deformation of small-diameter sewers constructed with flexible pipes, and of problems encountered in their construction. Inquiries indicated that the use of this type of pipe was increasing rapidly particularly for house drainage, in the construction of which less experienced labour and a minimum of supervision are available. A sub-committee was therefore appointed "to explore the possibility of producing notes for guidance in the laying of small-diameter flexible pipes for use as drains and sewers, and a note on their suitability for different ground conditions."

91. The sub-committee have sought evidence regarding the behaviour of pipes of this nature which have been in use for a reasonable period of time, but have found difficulty in obtaining such information related to known laying conditions. They have had discussions with representatives of the Pitch Fibre Pipe Association and the British Plastics Federation. These bodies have agreed to provide as much evidence as possible regarding their products and their long-term behaviour in the ground, and are continuing to collate information on this matter for the sub-committee.

92. Small-diameter flexible pipes derive their structural strength principally from the bedding on which they are laid and the sidefilling. It is therefore of great importance that suitable materials are used for bedding and sidefilling, and that they are properly compacted.

93. The best material in which to lay flexible pipes is a granular material of suitable grading, but the subsoil in its natural condition in some areas may be acceptable for the purpose. In these cases it would be unreasonable to suggest that satisfactory trench material must be replaced by imported granular bedding and sidefilling. The major difficulty lies in indicating to pipe users how they can decide whether a particular subsoil is satisfactory, since minor changes of grading may make a significant difference to the suitability of a material. Some pipe manufacturers are attempting to achieve the same object by advising users regarding the types of subsoil in which pipes should not be laid without imported bedding material. The sub-committee consider that a negative approach of this nature is not sufficient. They therefore approached the Director of the Building Research Station, and the Station has evolved simple tests designed to assess the suitability of soil material for surrounding flexible sewer and drain pipes laid underground.

94. The sub-committee are satisfied that a document giving information as to how small-diameter flexible pipes should be laid is urgently needed, and they have therefore prepared a note of guidance which is attached as an appendix to this report, and which includes details of the Building Research

Station tests. It is hoped that local authorities, professional institutions, trade associations and pipe manufacturers will co-operate with the Working Party in ensuring that it is disseminated as widely as possible to all those likely to use or supervise the construction of pipes of this nature.

Sub-committee No. 3

95. In discussion of practical difficulties of sewer construction the importance of the selection of suitable bedding for rigid pipes was stressed and a sub-committee was appointed "to consider the relative merits of various forms of bedding for rigid sewer pipes of various sizes laid at various depths and in various ground conditions, having particular regard to the present-day availability of plant, equipment, skilled labour and supervision, and in the light of possible future trends and development".

96. The sub-committee discussed a wide range of matters relating to different types of bedding and their relationships with the pipes to be used, ground conditions and methods of construction. They submitted to us their preliminary comments on various beddings, but were of the opinion that field tests were essential before they could reach any final conclusions.

97. We accepted this view and the sub-committee have prepared a programme of experimental work, which is described later in this report.

Sub-committee No. 4

98. In recent years general statements have been made which may have led to the belief that there has been widespread failure of sewers. In order to assess the extent to which established methods of design and construction are in fact deficient it is considered desirable that these statements should either be supported or refuted by definite quantitative and qualitative evidence, if this can be obtained. We have therefore appointed a sub-committee

> "to investigate the incidence of failure of sewers and drains, and if possible to give reasons for failures".

99. The sub-committee have considered the means whereby information of this nature can be obtained. They have accepted that it is impracticable to obtain absolute quantitative information regarding the incidence of failures throughout the country in relation to the total length of sewers and drains in existence, and that they must depend on sampling of representative examples of sewerage systems.

100. To obtain general information regarding failures they have been in touch with authorities known to have employed closed-circuit television for sewer surveys and are collating the information revealed by the surveys. They have approached the Institution of Municipal Engineers, who are assisting them by providing information as to districts in which failures are known to have occurred.

101. The sub-committee are bearing in mind that failure could be regarded as including both the inability to withstand imposed loads and lack of watertightness. They would welcome any specific information regarding failures known to have occurred, and any definite evidence regarding the extent of infiltration into sewerage systems.

102. They have noted with interest that so far as rigid pipes of 6 ins. diameter and under are concerned they have as yet had no evidence of instances of overload failure. Failures of such pipes are, however, known to have occurred through causes other than overload, such as inadequate bedding, inefficient backfilling and defective jointing.

103. They consider that information regarding failures will be particularly valuable if it can be related to the conditions and methods of construction of the sewers in question. They have in mind the possibility of inspecting sewers in limited drainage areas representative of modern sewerage systems by means of closed-circuit television. They would select areas with varying ground conditions and sewers of different sizes and materials. To this end they have attended a demonstration of sewer inspection by television.

Impact factor experiments

104. The calculation of the effect of superimposed loads involves the use of an empirical factor to allow for the impact effect of moving loads. In different parts of the world significantly different impact factors are employed, e.g. in the U.S.A. 1·5, in Australia 1·3 reducing to 1 at a depth of 3 feet, in Germany 1·6 reducing to 1·3 at a depth of 1 metre. In this country a factor of 2 has generally been used, which results in substantially higher calculated superimposed loads than elsewhere. Very little detailed experimental work appears to have been carried out on this matter and there is little definite evidence in support of any of the figures which have been adopted.

105. The factor has a significant effect on the design of sewers at depths of up to about 10 feet laid under roads. We therefore considered research work to be urgently necessary and had immediate consultations with the Ministry of Transport and the Road Research Laboratory. These bodies had intended for some time to carry out experiments on the problem and agreed to bring forward their work in view of the urgency in relation to our task.

106. We co-operated with them in preparing a programme of tests, which are now being carried out at Harmondsworth by the Laboratory. A length of road has been reconstructed, trenches excavated through it, sewers of different diameters laid at different depths, and the road reinstated. Various types of backfilling materials have been used in various trenches and the degree of compaction of the backfilling has been varied. Instruments have been installed to allow measurement of strain and deflection of the pipes and pressure in the soil at various depths below the road surface.

In the experiments, vehicles of various sizes and weights are being run over the trenches at various speeds and strain and pressure measurements recorded. It is hoped to use a wide range of vehicles up to one which will apply the Ministry of Transport HB loading. Practical conditions of poor trench reinstatement and vehicle overloading will be simulated during the course of the work.

107. It is expected that the work will be completed during the next few months and it is hoped that it will provide valuable knowledge of the transmission of moving surface loads to underground sewer structures and of the impact effects induced on rigid pipes by passing vehicles.

Our programme of experimental work

108. Arising out of the report of sub-committee No. 3 it became apparent that the immediate problems which had to be solved to enable us to pass judgment on different methods of design were:

(a) to ascertain the overall factor of safety of a sewer pipeline laid under practical conditions and subjected to normally occurring loads;

(b) to ascertain whether the theoretical predictions of the loads imposed on buried pipe sewers are reasonably correct;

(c) to ascertain whether the theoretical predictions of the supporting strengths of pipes laid on various beddings are reasonably correct.

109. To design a programme of experiments to cover all three objectives appeared to be impracticable and we decided that our first aim must be to determine the overall factor of safety (a), so that we could judge whether design methods were reasonable, or were under or over-estimating the strength required of a sewer pipeline. We have attempted to plan a programme of work so that it may provide us also with some information regarding the loads imposed on pipelines (b). The determination of bedding factors (c) we consider must be the subject of an entirely separate programme of experiments, which we hope to institute at a later stage of the work.

110. The vast range of variables in sewer design and construction cannot be covered by one programme of experiments, and in planning the experiments we have attempted only to reproduce a fair range of normal conditions.

111. The principle of the work is that a length of road of normal standard will first be constructed. Trenches will be excavated through it and lengths of 12 ins. diameter vitrified clayware and 36 ins. diameter unreinforced concrete pipes of known strength will be laid on various beddings at various depths. The road will then be reinstated.

Instruments will be installed to enable strain and deformation of the pipes to be measured and recorded. Static and transient loads will be imposed on the pipelines and the effect in terms of strain and deformation measured. The loads will continue to be increased and the strains recorded until structural failure of the sewers occurs, if this can be achieved.

112. The instrumentation of tests of this nature is difficult and complex and we have therefore sought the assistance of specialists in this field. They have met on several occasions and have prepared detailed proposals for us, for which we are indebted to them.

113. In order to establish a technique for the work, and to assess the practical difficulties, it was thought advisable to carry out a pilot test, on the results of which the details of the main programme will be based. The execution of work of this nature necessitates a suitable site, and constructional and scientific facilities. These exist at the Military Engineering Experimental Establishment, and the Director has kindly agreed to undertake the pilot test for us. The Concrete Pipe Association and the National Salt Glazed Pipe Manufacturers' Association are co-operating with us by providing and calibrating the pipes required for the work, and we gratefully acknowledge their help.

114. It is expected that the pilot tests will be completed this year and it is hoped to start the main programme as soon as possible afterwards.

115. The difficulties of experiments of this kind are fully realised, and we accept that the programme we have in mind may have to be extended and repeated in different ground conditions and with different combinations of the many variables. We are convinced, however, that it is only by practical field experiments of this nature that adequate knowledge of the behaviour of underground pipe sewers can be obtained.

* * * * *

116. In addition to the problems to which we have referred in this report, we accept the need for investigation of and hope in due course to study such matters as vehicle loads for which it is necessary to cater in sewer design; methods of and materials used for the backfilling of trenches; inspection, testing and maintenance of sewers and drains; and special methods of construction.

117. Our discussions and investigations to date have verified the urgent need for the work with which we have been entrusted, and have shown that economic and practical advantages could accrue from the successful completion of our task. We shall endeavour to submit a further report to you next year.

We have the honour to be,
Sir,
Your obedient Servants,

(Signed) R. A. Elliott (Chairman)
R. R. Beaumont
Granville Berry
R. T. Gillet
I. H. Hainsworth
J. M. Haseldine
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Secretaries

T. C. George

T. P. Hughes

31st October, 1965

APPENDIX

Note for guidance in the laying and backfilling of flexible sewer and drain pipes, such as pitch fibre or p.v.c.

1. The properties that give flexible pipes, such as those made of pitch fibre or plastics, their valuable attribute of longitudinal flexibility may also result in excessive deformation or ovality of cross section unless care is taken during installation to ensure that the pipes are given adequate bedding and side support, since it is from these that the pipes principally derive their strength.

Certain precautions are necessary when any type of pipe is laid if subsequent failure is to be avoided. For convenience the principal precautions are summarised here together with those requiring special attention with pitch fibre and plastics pipes.

The Working Party consider that construction in accordance with this note is the most satisfactory method of laying flexible sewer and drain pipes so far as this can be determined by information and experience available at the present time. It may be possible to make the recommendations given at the end of this note less stringent as the result of long-term trials being carried out by the Building Research Station and in the light of further field experience.

Excavation

2. The trench should not be opened too far in advance of pipe laying and should be backfilled as soon as possible. The width of the trench at the crown of the pipe should be as narrow as practicable, but not less than the outside diameter of the pipe plus one foot to allow proper compaction of the sidefill. Above the crown of the pipe the trench may be of any convenient width.

The trench should be excavated to the depth below the invert of the pipe that will allow any necessary bedding (see paragraph 4). Before placing this bedding the trench bottom should be prepared. All soft spots should be hardened by tamping in gravel or broken stone. Rock projections should be removed. In fine grained soils such as soft clays, silts or fine sand, disturbance of the bottom of the trench should be prevented by placing a layer of bedding material 3 ins. thick on the virgin surface before permitting traffic on the bottom.

Material for bedding and sidefill for flexible pipes

3. Clay should never be used for bedding, sidefill or backfill immediately around the pipe. It is not possible to compact it sufficiently and it is liable to swell.

Some other soils, however, as excavated from the trench, such as free-draining coarse sand, gravel, loam and soils of a friable nature may be suitable, but must be capable of being compacted sufficiently to provide support for the pipe. Soils such as hard chalk which break up when wet should not be used.

A simple method devised by the Building Research Station of testing the excavated material to determine whether it possesses the requisite properties is described at the end of this note.

Should the material excavated from the trench be unsuitable then granular material must be imported. The most suitable is gravel or broken stone from $\frac{3}{8}$ to $\frac{3}{16}$ in. in size since it requires little tamping, but coarse sand, or sand and gravel, or gravel from $\frac{3}{4}$ in. down as it comes from the quarry is acceptable provided it complies with the B.R.S. tests described at the end of the note. An excess of fine particles makes the mixture more difficult to compact when damp.

Bedding and sidefilling

4. With flexible pipes it is of great importance that the sidefill should be very firmly compacted between the sides of the pipe and the soil sides of the trench. Any trench sheeting should if necessary be partially withdrawn to allow this to be done. The thickness of the bedding under the barrel of the pipe should be a minimum of 4 ins. for pipes up to 8 ins. in diameter. In very soft or wet conditions or where the bottom of the trench is very irregular this thickness should be increased as necessary to give a suitable bed.

The bedding should be thoroughly compacted in layers not more than 6 ins. thick to give a uniform bed, true to gradient, on which the pipe may be laid. Pipes should be laid directly on this bedding. Bricks or other hard material must not be placed under the pipes for temporary support.

After the pipes have been laid and tested further bedding material should be placed around the pipe and be thoroughly compacted in 3 in. layers by careful tamping up to the crown of the pipe, eliminating all cavities under the two lower quadrants of the pipe.

The same material should then be placed over the crown of the pipe for a minimum height of 4 ins. for 4 ins. diameter pipes and 6 ins. for 6 ins. and 8 ins. diameter pipes and be thoroughly compacted. The process of filling and tamping should proceed equally on either side of the pipe so as to maintain an equal pressure on both sides.

Backfilling

5. Normal filling of the trench should then proceed in layers not exceeding 12 ins. in thickness, each layer being well rammed. Heavy mechanical rammers should not be used until the fill has reached a depth of 12 ins. above the top of the pipe.

Special consideration and selection of backfilling material will be necessary if the risk of surface subsidence is an important consideration, for example under roads.

Use of concrete

6. Generally the use of concrete with flexible pipes is wasteful since it converts a flexible pipeline into a beam of negligible flexural strength which will fracture under minor ground movement. With more than 2 feet of cover concrete is normally unnecessary.

With less than 18 ins. of cover, elsewhere than under roads, narrow concrete slabs on a cushion of filling material above the pipe should be used as protection against picks etc. At shallow depths under roads etc. special consideration should be given to all the engineering factors involved, such as the class of road, its construction, and the proximity of other services.

At or above ground level concrete surround should be used to protect the pipe.

Special cases

7. For special cases of unstable ground and areas of mining subsidence where "draw" of the joints may be expected, telescopic joints should be employed throughout the line though most flexible pipes are capable of following ground movement of normal degree without fracture or failure.

Maximum allowable deformation

8. For the necessary reaction from the sidefill to develop it is necessary for some deformation or ovality of the pipe to take place. Until more is known on this subject the Building Research Station consider that the maximum acceptable decrease in vertical diameter is 5%, because above this figure there is increasing risk of blockage, leakage from the joints or collapse of the pipes. With the granular material previously described the decrease in vertical diameter will probably be considerably less than this figure. Whether 5% is acceptable in any particular case must be for the design engineer to decide.

Tests for suitability of soil material for surrounding flexible sewer and drain pipes laid underground

(a) *Particle size*

The maximum particle size should generally not exceed ¾ in. The presence of an occasional particle between ¾ in. and 1½ ins. is acceptable provided the total quantity of such particles is only a very small fraction of the whole. If particles over 1½ ins. are present the material should be rejected.

In cases of doubt a weighed representative* sample of material (about 5 lbs.) should be sieved†, using ¾ in. and 1½ ins. B.S. sieves. If (i) any particles are retained on the 1½ ins. sieve, or (ii) more than 5% by weight of the sample is retained on the ¾ in. sieve, the material is not acceptable, unless it is first screened so as to comply with this requirement.

(b) *Ease of compaction*

Apparatus required

1. Open-ended cylinder 10 ins. long and 6 ins. ± ¼ in. internal diameter (6 ins. diameter pitch fibre or p.v.c. pipe is suitable);
2. metal rammer with striking face 1½ ins. diameter and weighing 2 to 2½ lbs.;
3. rule.

Method

Obtain a representative* sample more than sufficient to fill the cylinder (viz. about 25 lbs.). It is important that the moisture content of the sample should not differ materially from that of the main body of material at the time of its use in the trench.

Place the cylinder on a firm flat surface and gently pour the sample material into it, *loosely and without tamping*. Strike off the top surface level with the top of the cylinder and remove all surplus spilled material. Lift the cylinder up clear of its contents and place on a fresh area of flat surface. Place about one quarter of the material back in the cylinder and tamp vigorously until no further compaction can be obtained. Repeat with the second quarter, tamping as before, and so on for the third and fourth quarters, tamping the final surface as level as possible.

Measure down from the top of the cylinder to the surface of the compacted material. This distance in inches divided by the height of the cylinder (10 inches) is referred to as the Compaction Fraction.

Compaction Fraction	*Suitability for use*
0·1 or less	Material suitable.
0·1 to 0·3	Material suitable but requires extra care in compaction. Not suitable if the pipe is subject to waterlogged conditions after laying.
Over 0·3	Material unsuitable.

Notes

* To obtain a representative sample about 1 cwt. of the proposed material should be heaped on a clean surface and divided with the spade down the middle into two halves. One of these should then be similarly divided, and so on until the required weight of sample is left.

† In the sieving, clumps of material that break up under light finger pressure may be helped through the sieve, but considerable force must *not* be used to squeeze oversize clumps through the mesh.

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